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Research Article

Iran's Steel Chain Interactive Network Mapping

M. H. Sadat Hosseini Khajouei [1], N. Pilevari *[2], R. Radfar [3], A. Mohtashami [4]

[1] *Department of Management and Economics Islamic Azad University Science and Research Branch Tehran Iran*
[2] *Department of Industrial Management College of management and accounting Islamic Azad University West Tehran Branch Tehran Iran*
[3] *Department of Management and Economics Islamic Azad University Science and Research Branch Tehran Iran*
[4] *Department of Industrial Management, Qazvin Branch, Islamic Azad University, Qazvin, Iran*

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ABSTRACT

Steel Supply Chain (SSC) is a interpretative segment in Steel's value-creation process for ensuring on-time delivery of the right quality of raw materials, Work In Process (WIP), other goods and services to manufacturing sites, and finished products to the ultimate consumers. Graph theory provides a real-time, end-to-end view of the Steel supply chain, from suppliers to customers. By representing the supply chain as a network of interconnected nodes, graph theory provides a visual representation of the relationships between nodes including: suppliers, manufacturers, distributors, and customers. The main purpose of this study is to focus on Iran's Steel Supply Chain (ISSC) based on complex adaptive network analysis and graph theory. Data collection performed by steel industry monitoring reports produced by relevant organizations. By mapping the Iranian SSC to the network in the Gephi environment (0.9.2), the graph theory applied to analyze node-level and network-level indices. This hypothesis tested that the corresponding network of the target SSC contained a Complex Adaptive System (CAS) which is an inception to combining social science insights to develop systems-level models and insights that allow for phase transitions and emergent behavior.

1. Introduction

The reductionist view is to simplify the structure of complexity by creating a model. Basically, it ia important to know the differentiate between scale models, analog models, and theoretical models is needed (Sadat Hosseini Khajouei et al., 2021). An analogy model shows an object in another object that has a similar structure (homomorphism). The theoretical model contains a set of assumptions and equations that you can use to understand the basic properties of an object or system. On the other hand, Programming languages lost the efficiency and agility of simple models, and scientists embarked on looking for solutions to problems of varying complexity. Researchers are trying to overcome the complexity of component interactions and inherent connectivity by adopting a variety of hardware, software, and programming skills (Wilensky and Rand, 2015). Wilensky and Rand (2015) introduced two major categories of modeling. In Phenomenon-based modeling, modeler aims to have reference patterns, starting with reference phe-

**Corresponding author*
Email: pilevari.nazanin@wtiau.ac.ir
Address: Department of Industrial Management College of management and accounting Islamic Azad University West Tehran Branch Tehran Iran
1. Ph.D. Candidate, 2. Professor, 3. Professor, 4. Associate Professor

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nomena and getting a set of agents and rules to control them. In exploratory-based modeling, modeler identifies emerging patterns by creating agents and defining their behaviors.

Since the Iran's steel industry is constantly facing challenges with new competitive materials, increased imports, passage of by-product import and export legislation, increased labor costs and more complex technologies, this research presents a mapping based on graph theory of the steel supply chain in Iran. First assumption concerns the mapping of supply chains to social networks (Borgatti and li, 2009). Another one is that social network analysis is based on graph theory (Cook et al., 1983). Graph theory is an important mathematical tool in a wide variety od subjects, ranging from operational research and chemistry to genetics and linguistics, and from electrical engineering and geography to sociology and architecture (Wilson, 1996). Graphs are visual representations of data. Graph theory is useful because it is powerful tools that can be used for things like data analysis, emphasizing a point, or comparing multiple sets of data in a way that is easy to understand and use. In this research, via way of means of mapping a steel chain as a complex adaptive system to a social network, network analysis and assessing of node and network level indices via the fundamentals of graph theory. Iran's SSC mapped using Gephi (version 0.9.2) as input for further analysis to use the collected data to extract the variables and parameters needed for a wide range of applications. The rationale for this approach is to pay attention to the grid and visual characteristics of the steel network and to create a platform that allows the visualization and investigation for different types of steel network in terms of representation and topology.

The remainder of this paper is as follows: Section 2 presents a review of the related literature. Section 3 explains the research process as well as the extracted indicators and the conceptual model. Section 4 is devoted to calculation od node and network level indicators. Section 6 presents the findings and conclusion.

2. Literature Review

Steel Supply chains are constantly being challenged by costs of unknown origin. To overcome this ambiguity, the supply chain network must be treated as a interactive network. Different topological structures (Perera et al., 2017; Modrak and Bednar, 2016), different products, entities, resources, processes, and their different characteristics, different members and their different roles, financial, information between them and materials flows, and interactions and interdependence can be the reason for the complexity of the supply chain networks. Many aspects, including structural complexity, openness, emergence, and dynamics, reflect the complexity of supply chain networks (Wang et al., 2018).

A key understanding is that the SSC network must be considered as a complex system (Sadat Hosseini Khajouei et al., 2021). There are numerous barriers in the industry, and one effective solution to further simplify the promotion of resilience goals is to map Iran's steel chains to the network (graph) and follow the node and network indices. It's about analyzing the resilience of our network. This study proposes graph based modeling as a way to track Iran's steel industry supply chain behavior in crisis situations and evaluate new scenarios. The modeling approach needs to take into account the nature of the decisions made about the various elements that make up the SSC. Given the changing goals of decision makers, the transient behavior of some subsystems (sub-industries of the steel industry) should also be considered based on knowledge of the environment in which other decision makers and SSC are involved. This enables a strong chain structure of this strategic commodity and operational strategies in all its subsystems. Goyal et al. (2018) evaluated and compared the environmental sustainability performance of supply chain for Indian steel industry using graph theoretic approach (GTA). Sharifi and Hadi (2014) presented an intuitive procedure for the shape and sizing optimizations of open and closed thin-walled steel sections using the graph theory. They found shapes of optimum mass and strength (bi-objectives). Nakatani et al. (2017) developed a methodology for vulnerability assessment of supply chains. In their research, raw material-to-product links and overall chain are modeled by a directed graph.

Anteractive network mapping refers to the process of creating visula representations of a network (e.g., supply chain) that allows users to explore and manipulate data, Nuss et al., (2016) mapped supply chains for five product platforms (a cadmium telluride solar cell, a germanium solar cell, a turbine blade, a lead acid battery, and a hard drive magnet) using a data ontology that specifies the supply chain actors (nodes) and linkages (e.g., material exchange and contractual relationships) among them. Nuss et al., (2016) proposed a set of network indicators (product complexity, producer diversity, supply chain length, and potential bottlenecks) to assess the situation for each platform in the overall supply chain networks. They constructed supply chain according to the SMART data structure and then imported into the Gephi 0.8.2 beta network analysis software for further analysis. To explore in detail the relationships connecting materials to the products that require them, MacCarthy et al. (2022) illustrated the hierarchy with a range of examples from the textile and apparel industry. they identified the primary and secondary data sources that can underpin mapping studies, highlighting the significant challenges in using them.

The literature review demonstrates that very few cases have dealt with the mapping of the Steel supply chain of Iran. This research is conducted to answer the following two basic questions:

I. What network topological metrics can be used as an index to measure Steel chain performance?

II. How to use this metrics to determine the critical nodes/ links in Steel chain network?

3. Methodology

This article is based on Conte's positivist philosophy of social reality (in terms of interactions, dependencies and intrinsically complex relationships) using conceptual frameworks, observation and measurement techniques, and mathematical analysis and computation. The main goal of this study is to map Iran's Steel supply chain using graph theory. By mapping Iran's steel supply chain to a network, using graph theory, node level and network level indices such as in-degree, out-degree, centrality, betweenness, network density, average path length and network centrality, as well as network topology. In this study, the Gephi software version (0.9.2) used in the realm of network analysis, index evaluation, and network design. Gephi is a tool for data analsis to explore graphs and networks. Gephi software has Excel-like data laboratory to input, search and manipulate data. It supports Comma-Seperated Values (CSV) files. Data collection was performed by reviewing the steel industry monitoring reports produced by relevant organizations including Iranian Mines & Mining Industries Development & Renovation (IMIDRO) and mininstry of industry, mine and trade of Iran. This data plays a key role in determining the boundaries of the model. In this research, Iron ore-producing mines (Magnetite and Hematite), 67% concentrate production lines, pellet production plants, sponge iron production plants (by PERED or MIDREX process), and steelmakers (blast furnace and induction furnace) are collected.

SSC consists of 5 tiers depending on the production method. The main material for steel production is iron ore. The main variables are the number of perturbation-prone nodes, disturbed nodes and responding nodes, the initial number of disturbed nodes, the rate of redundancy, the sequence of checking the status of the disturbing agents, and the predicted resistance. Note that in the process of mapping SSCs as a complex adaptive system to social networks, all parameters, including node and network level indices calculated based on the flow of material and the capacity of mining units and plants. The theoretical foundation of steel chain in the proposed framework is based on Liu et al. (2017) and Sandhu et al. (2011). After crushing, granulating and concentrating, the iron ore lump is less than 1 millimeter and its garde is 67%. However, these dimensions are not suitable for direct use in blast furnaces and electric arc furnaces. Therefore, it is necessary to carry out the agglomeration process. This creates a larger granular material. The most common method of agglomeration is pelletization. This process converts 67% concentrate in dimensions from 45 microns to 1 mm to dimensions from 6 to 16 mm. The pellets are converted to molten crude iron, also known as cast iron, in the blast furnace process. Cast iron becomes steel in an oxygen furnace. In the direct reduction process, pellets are converted to sponge iron using techniques such as PERED or MIDREX. This material can be used in induction furnaces. Both sponge iron and scrap can also be converted to steel by induction furnaces.

The steel chain was explained as this study was originally intended to identify a phenomenon that needs to be studied. Therefore, the steel chain investigated in this study is presented as shown in Fig. 1. The proposed model includes production parts such as mines, concentrate units, pelletizing plants, sponge iron and steel units. The basis of steel industry is based on Iron, so secondary materials such as coke, scrap, graphite electrode, bentonite, oxygen, lime, dolomite, etc. have been avoided. Because of the lack of adequate documentation, the intervention of secondary materials in the model delineation phase and the model boundary determination were rejected. The casting process as well as the production of finished and semi-finished products are not part of the steel chain because they are very diverse; as they are all manufactured from ingot steel.

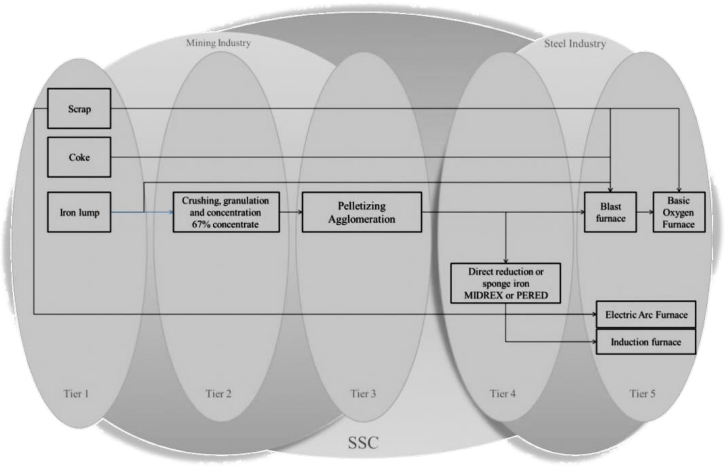


Fig. 1. SSC framework and model boundaries.

4. Node And Network Level Parameters

Network density is the ratio between the actual number of edges and the maximum possible number of edges. Network density Measurement provides insights into how complex and connected supply chain networks are (Scott, 2000). As shown in Fig. 2. a dense network has more operational effort and more coordination overhead to survive. Higher network density with one more member means more robust and less resilient.

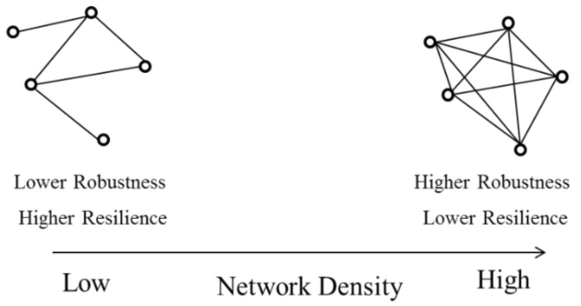


Fig. 2. Low density vs. high density network with resilience approach.

Average path length (APL) is the average distance between the shortest paths of all possible node pairs. A shorter path between two nodes means faster material flow. Therefore, network robustness can be analyzed by comparing the average path lengths before and after the interference. Centrality is defined as the percentage of the overall network connectivity that can be attributed to a particular node. A fully centralized network is less robust because when important nodes are directly or indirectly disrupted, it causes a ripple effect for other nodes. The control of a highly centralized network depends on several nodes. If these nodes are active, disrupting other nodes can quickly activate control nodes and restore the supply chain. Therefore, the resilience of such networks cannot be concluded with certainty. The betweenness centrality of the network refers to network member's role in the pickup (document collection) and delivery (distribution) of materials (Yan et al., 2011). This means that a large number of nodes dependend on an intermediate node. Therefore, it may be a more precise criterion than centrality for robustness. Betweenness is defined as Eq.(1), where σ(i,j) is a the number of shortest paths between nodes i and j, and σ(i,k,j) is the number of shortest paths between i and j that go through node k.

Eq.(1)

$$betweenness\ (k) = \sum_{i \neq j \neq k} \frac{\sigma(i,k,j)}{\sigma(i,j)}$$

Eq.(2)

$$clossness\ centrality\ (k) = \left(\sum_{t \in \mathrm{N}} \iota(k,t)\right)^{-1}$$

Eq.(3)

$$centrality\ (k) = \left(\max_{t \in \mathrm{N}} \iota(k,t)\right)^{-1}$$

Table 1. Node and network level parameters and their initial values for the SSC network of Iran for mines nodes.

Id	Label	Node Type	potential capacity	indegree	outdegree	Degree	Eccentricity	closnesscentrality	harmonicclosnesscentrality	betweenesscentrality	Authority	Hub	modularity_class	pageranks	strongcompnum
0	SANGAN.M	Mine	30000000	0	3	3	4	0.350877	0.4375	0	0	0	3	0.003883	20
1	JALALABAD.M	Mine	6000000	0	2	2	4	0.314286	0.358586	0	0	0	5	0.003883	49
2	CHADORMALOU.M	Mine	14750000	0	1	1	4	0.326087	0.377778	0	0	0	1	0.003883	55
5	GISDCO.M	Mine	19000000	0	3	3	4	0.325397	0.378049	0	0	0	1	0.003883	59
7	CHAH GAZ.M	Mine	2000000	0	1	1	1	1	1	0	0	0	6	0.003883	60
8	SECHAHOUN.M	Mine	2000000	0	1	1	4	0.333333	0.375	0	0	0	2	0.003883	63
10	CHOGHART.M	Mine	3000000	0	1	1	4	0.333333	0.375	0	0	0	2	0.003883	64
11	SISOO.M	Mine	970000	0	1	1	4	0.357143	0.466667	0	0	0	7	0.003883	67
12	ESMALOUN.M	Mine	6650000	0	1	1	4	0.4	0.520833	0	0	0	0	0.003883	69
13	SHAHRAK.M	Mine	750000	0	1	1	4	0.368421	0.452381	0	0	0	8	0.003883	72
14	BABA ALI.M	Mine	600000	0	1	1	4	0.352941	0.444444	0	0	0	2	0.003883	74
15	GALALI.M	Mine	250000	0	1	1	4	0.352941	0.444444	0	0	0	2	0.003883	75
16	AJZ.M	Mine	460000	0	1	1	4	0.4	0.520833	0	0	0	8	0.003883	77
17	ZNG.M	Mine	1000000	0	1	1	4	0.368421	0.452381	0	0	0	6	0.003883	79
18	REZWAN.M	Mine	2000000	0	1	1	4	0.35	0.428571	0	0	0	5	0.003883	81
19	SORKHEDIZAJ.M	Mine	400000	0	1	1	4	0.368421	0.452381	0	0	0	6	0.003883	83
20	AK KAHOUR.M	Mine	200000	0	1	1	4	0.4	0.520833	0	0	0	8	0.003883	85
21	PELS.M	Mine	2500000	0	1	1	4	0.318182	0.369048	0	0	0	4	0.003883	88
22	SARAB.M	Mine	150000	0	1	1	4	0.344828	0.408333	0	0	0	6	0.003883	90

Table 2. Node and network level parameters and their initial values for the SSC network of Iran for concentrate nodes.

Id	Label	Node Type	potential capacity	indegree	outdegree	Degree	Eccentricity	closnesscentrality	harmonicclosnesscentrality	BETWEENESSCENTRALITY	Authority	Hub	modularity_class	pageranks	strongcompnum
23	OPALKANI.C	Consentrate	2600000	1	1	2	3	0.413793	0.458333	11	0	0	3	0.005048	19
24	EHYAA.C	Consentrate	3100000	1	2	3	3	0.433333	0.5	13	0	0	4	0.007377	87
25	SIMIDCO.C	Consentrate	2500000	1	2	3	3	0.571429	0.708333	4	0	0	3	0.005048	8
26	SBNK.C	Consentrate	1000000	1	2	3	3	0.5	0.611111	6	0	0	8	0.007377	71
27	SBNH.C	Consentrate	600000	2	1	3	3	0.454545	0.533333	10	0	0	2	0.010872	73
28	GISDCO.C	Consentrate	14750000	0	5	5	3	0.438596	0.52	0	0	0	5	0.003883	97
29	MIDHCO.C	Consentrate	8000000	2	1	3	3	0.405797	0.434524	40.233333	0	0	1	0.006795	48
30	GZ.C	Consentrate	6000000	1	5	6	3	0.458333	0.545455	13.033333	0	0	1	0.005048	58
31	AJIK.C	Consentrate	500000	1	1	2	3	0.5	0.611111	3	0	0	8	0.007377	76
32	AJIY.C	Consentrate	1000000	1	1	2	3	0.5	0.611111	3	0	0	0	0.007377	68
33	GISDCO.C	Consentrate	10500000	2	3	5	3	0.451613	0.535714	21.9	0	0	1	0.008542	54
34	ICIOC.C	Consentrate	5000000	2	7	9	3	0.480769	0.58	50	0	0	2	0.010872	62
35	FKS.C	Consentrate	600000	1	3	4	3	0.464286	0.551282	7.833333	0	0	5	0.00563	34
36	SHND.C	Consentrate	1200000	1	2	3	3	0.5	0.611111	6	0	0	6	0.007377	78
37	NFY.C	Consentrate	300000	1	1	2	3	0.444444	0.541667	4	0	0	7	0.007377	66
38	RZWN.C	Consentrate	600000	1	1	2	3	0.461538	0.527778	6	0	0	5	0.007377	80
39	KIMS.C	Consentrate	300000	1	2	3	3	0.473684	0.555556	9	0	0	6	0.007377	89
40	SMRN.C	Consentrate	1200000	0	1	1	3	0.461538	0.527778	0	0	0	5	0.003883	98
41	SAF.C	Consentrate	550000	0	1	1	3	0.5	0.611111	0	0	0	7	0.003883	100
42	JHNN.C	Consentrate	350000	1	2	3	3	0.5	0.611111	6	0	0	6	0.007377	82
43	AKK.C	Consentrate	180000	1	1	2	3	0.5	0.611111	3	0	0	8	0.007377	84
44	SNGCO.C	Consentrate	5000000	1	1	2	3	0.5	0.611111	2	0	0	3	0.005048	3

Table 3. Node and network level parameters and their initial values for the SSC network of Iran for pellets nodes.

Id	Label	Node Type	potential capacity	indegree	outdegree	Degree	Eccentricity	closnesscentrality	harmonicclosnesscentrality	BETWEENESSCENTRALITY	Authority	Hub	modularity_class	pageranks	strongcompnum
45	MSC.P		Pellet	7200000	9	1	10	2	0.666667	0.75	27.833333	0	0.105343	8	0.036785
46	SNGCO.P		Pellet	5000000	1	1	2	2	0.666667	0.75	3	0	0.105343	8	0.008426
47	OPALKANI.P		Pellet	5000000	2	5	7	2	0.647059	0.727273	41	0	0.206868	3	0.009459
48	KHRSN.P		Pellet	2500000	2	1	3	2	0.666667	0.75	4	0	0.010384	4	0.009559
49	KSC.P		Pellet	6000000	8	1	9	2	0.666667	0.75	30	0	0	6	0.020704
50	MIDHCO.P		Pellet	7500000	1	13	14	2	0.658537	0.740741	65.233333	0	0.72641	1	0.009998
51	GISDCO.P		Pellet	10000000	1	5	6	2	0.608696	0.678571	13.166667	0	0.296048	5	0.006818
52	SBN.P		Pellet	550000	2	2	4	2	0.666667	0.75	18	0	0.130382	2	0.014663
53	CHML.P		Pellet	3400000	1	3	4	2	0.636364	0.714286	18.4	0	0.081065	1	0.007282
54	ARSCO.P		Pellet	300000	1	1	2	2	0.6	0.666667	6	0	0.03839	7	0.010522
55	GZ.P		Pellet	5000000	1	6	7	2	0.65	0.730769	14.366667	0	0.446968	1	0.006363
56	OMID.P		Pellet	600000	1	1	2	2	0.666667	0.75	2	0	0.036463	7	0.007377
57	MAAD.P		Pellet	2500000	6	3	9	2	0.714286	0.8	51.666667	0	0.229456	5	0.019655
58	ARSCO.P		Pellet	600000	2	1	3	2	0.6	0.666667	13.333333	0	0.03839	7	0.004812
59	SIMIDCO.P		Pellet	2500000	1	1	2	2	0.666667	0.75	2	0	0	6	0.007335
60	ICIOC.P		Pellet	5000000	1	3	4	2	0.666667	0.75	12	0	0.186596	2	0.00912
61	PASCO.P		Pellet	3400000	3	1	4	2	0.666667	0.75	11	0	0.036463	2	0.007128
62	ESF.P		Pellet		3	1	4	2	0.666667	0.75	10	0	0.056214	6	0.007373

Table 4. Node and network level parameters and their initial values for the SSC network of Iran for DRI nodes.

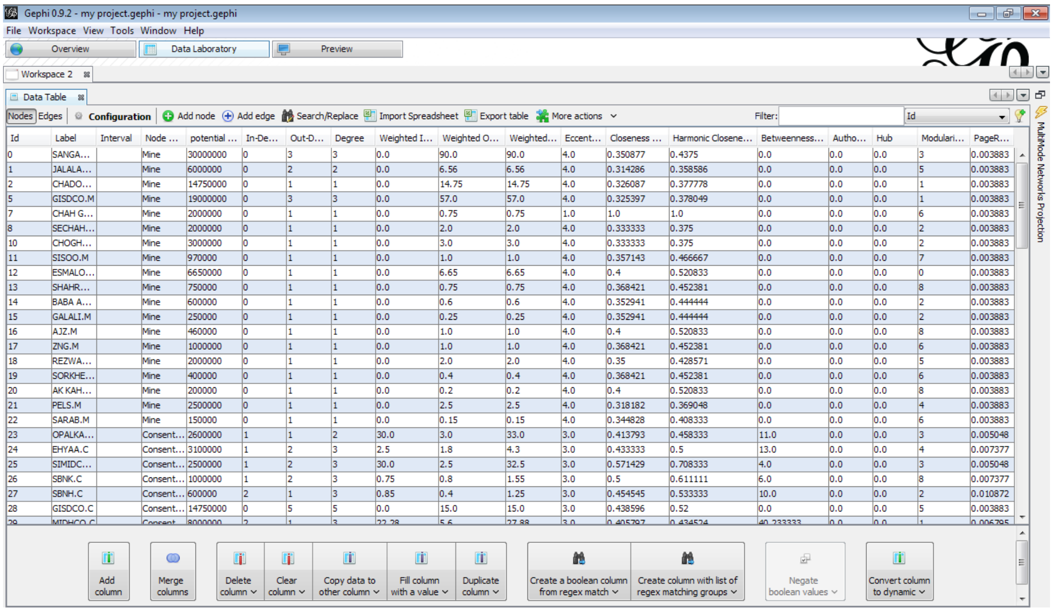
Id	Label	Node Type	potential capacity	indegree	outdegree	Degree	Eccentricity	closnesscentrality	harmonicclosnesscentrality	BETWEENESSCENTRALITY	Authority	Hub	modularity_class	pageranks	strongcompnum
63	MSS.D	DRI	10400000	8	1	9	1	1	1	35.166667	0.481843	0	8	0.062981	
64	KHRSN.D	DRI	1600000	2	1	3	1	1	1	7	0.047497	0	4	0.014205	
65	SSICO.KSC.D	DRI	4800000	2	1	3	1	1	1	18	0	0	6	0.029119	
66	SJSCO.D	DRI	800000	1	1	2	1	1	1	2	0.064724	0	5	0.004608	
67	GISDCO.D	DRI	3400000	1	7	8	1	1	1	11.833333	0.064724	0	5	0.006601	
68	MIDHCO.D	DRI	800000	1	1	2	1	1	1	4	0.158812	0	1	0.005921	
69	HOSCO.D	DRI	1700000	4	1	5	1	1	1	18	0.37142	0	5	0.010677	
70	SKSCO.D	DRI	1850000	4	1	5	1	1	1	17	0.37142	0	5	0.01341	
71	IGISCO.D	DRI	800000	2	3	5	1	1	1	13.9	0.176535	0	1	0.005814	
72	ARFA.D	DRI	800000	2	1	3	1	1	1	3.5	0.176535	0	1	0.005644	
73	PGSEZ.D	DRI	1500000	3	0	3	0	0	0	0	0.306696	0	1	0.01082	
74	AZRB.D	DRI	800000	3	1	4	1	1	1	15	0.114526	0	2	0.014749	
75	NGHSCO.D	DRI	800000	2	1	3	1	1	1	6	0.256531	0	1	0.005379	
76	SPSCO.D	DRI	800000	1	2	3	1	1	1	10	0.045227	0	3	0.007048	
77	CHML.D	DRI	1550000	1	2	3	1	1	1	5.7	0.017723	0	1	0.007569	
78	ESF.D	DRI	200000	4	1	5	1	1	1	17	0.257123	0	6	0.01134	
79	BAFT.D	DRI	800000	2	3	5	1	1	1	15.9	0.256531	0	1	0.005396	
80	ARSCO.D	DRI	960000	3	2	5	1	1	1	22.166667	0.175599	0	7	0.017863	
81	GSCO.D	DRI	800000	2	1	3	1	1	1	3.833333	0.166784	0	7	0.010733	
82	PASCO.D	DRI	1800000	2	1	3	1	1	1	10	0.166784	0	2	0.010825	

Table 5. Node and network level parameters and their initial values for the SSC network of Iran for steel nodes.

Id	Label	Node Type	potential capacity	indegree	outdegree	Degree	Eccentricity	closnesscentrality	harmonicclosnesscentrality	BETWEENESSCENTRALITY	Authority	Hub	modularity_class	pageranks	strongcompnum
83	MSS.S	Steel	9600000	2	0	2	0	0	0	0	0	0	8	0.061769	
84	KHRSN.S	Steel	1250000	1	0	1	0	0	0	0	0	0	4	0.016668	
85	KSC.S	Steel	2800000	1	0	1	0	0	0	0	0	0	6	0.030091	
86	SJSCO.S	Steel	1000000	1	0	1	0	0	0	0	0	0	5	0.00803	
87	INSIG.S	Steel	420000	1	0	1	0	0	0	0	0	0	5	0.004603	
88	MIDHCO.S	Steel	1000000	1	0	1	0	0	0	0	0	0	1	0.009212	
89	HOSCO.S	Steel	1500000	1	0	1	0	0	0	0	0	0	5	0.013492	
90	SKSCO.S	Steel	2400000	2	0	2	0	0	0	0	0	0	5	0.017032	
91	KSI.S	Steel	600000	1	0	1	0	0	0	0	0	0	5	0.004603	
92	ARFA.S	Steel	800000	2	0	2	0	0	0	0	0	0	1	0.010231	
93	VIAN.S	Steel	550000	2	0	2	0	0	0	0	0	0	2	0.021998	
94	IASCO.S	Steel	550000	3	0	3	0	0	0	0	0	0	1	0.008351	
95	NTNZ.S	Steel	1000000	2	0	2	0	0	0	0	0	0	5	0.005456	
96	KHZR.S	Steel	500000	2	0	2	0	0	0	0	0	0	5	0.008411	
97	CHML.S	Steel	1000000	1	0	1	0	0	0	0	0	0	1	0.009938	
98	ESF.S	Steel	2600000	2	0	2	0	0	0	0	0	0	6	0.017583	
99	YZDRM.S	Steel	300000	2	0	2	0	0	0	0	0	0	5	0.005562	
100	MFBCO.S	Steel	450000	1	0	1	0	0	0	0	0	0	1	0.007121	
101	PASCO.S	Steel	1500000	1	0	1	0	0	0	0	0	0	2	0.013626	
102	ESFST.S	Steel	200000	1	0	1	0	0	0	0	0	0	3	0.006538	
103	RUHN.S	Steel	480000	1	0	1	0	0	0	0	0	0	7	0.013776	
104	ANA.S	Steel	1000000	2	0	2	0	0	0	0	0	0	7	0.019726	

Table 1. to table 5. show the agents, nodes and network-level parameters for the Iranian SSC network and their initial values. Various graph file formats can be used as inputs for Gephi software. The collected data organized in a CSV format and within Excel software. It considered as an input for data laboratory in the Gephi (0,9,2) to customize nodes and links. As can be considered in Fig. 3. the data laboratory displays a table with rows corresponding to nodes and links and columns representing attributes such as size and color. After choosing a layout algorithm to arrange nodes, by experiment with defferent layouts, the most suitable one found.

Fig. 4. shows mapped network of Iran's steel chain. According to relevent literature, since a robust supply chain possesses a higher degree of betweenness, and the resilience of the supply chain is proportional to the centrality, these two attributes considered for visual representation of the proposed network.



Id	Label	Interval	Node ...	potential ...	In-De...	Out-D...	Degree	Weighted I...	Weighted O...	Weighted...	Eccent...	Closeness ...	Harmonic Closene...	Betweenness...	Autho...	Hub	Modulari...	PageR...
0	SANGA...		Mine	30000000	0	3	3	0.0	90.0	90.0	4.0	0.350877	0.4375	0.0	0.0	0.0	3	0.003883
1	JALALA...		Mine	6000000	0	2	2	0.0	6.56	6.56	4.0	0.314286	0.358586	0.0	0.0	0.0	5	0.003883
2	CHADO...		Mine	14750000	0	1	1	0.0	14.75	14.75	4.0	0.326087	0.377778	0.0	0.0	0.0	1	0.003883
5	GISDCO.M		Mine	19000000	0	3	3	0.0	57.0	57.0	4.0	0.325397	0.378049	0.0	0.0	0.0	1	0.003883
7	CHAH G...		Mine	2000000	0	1	1	0.0	0.75	0.75	1.0	1.0	1.0	0.0	0.0	0.0	6	0.003883
8	SECHAH...		Mine	2000000	0	1	1	0.0	2.0	2.0	4.0	0.333333	0.375	0.0	0.0	0.0	2	0.003883
10	CHOGH...		Mine	3000000	0	1	1	0.0	3.0	3.0	4.0	0.333333	0.375	0.0	0.0	0.0	2	0.003883
11	SISOO.M		Mine	970000	0	1	1	0.0	1.0	1.0	4.0	0.357143	0.466667	0.0	0.0	0.0	7	0.003883
12	ESMALO...		Mine	6650000	0	1	1	0.0	6.65	6.65	4.0	0.4	0.520833	0.0	0.0	0.0	0	0.003883
13	SHAHR...		Mine	750000	0	1	1	0.0	0.75	0.75	4.0	0.368421	0.452381	0.0	0.0	0.0	8	0.003883
14	BABA A...		Mine	600000	0	1	1	0.0	0.6	0.6	4.0	0.352941	0.444444	0.0	0.0	0.0	2	0.003883
15	GALALI.M		Mine	250000	0	1	1	0.0	0.25	0.25	4.0	0.352941	0.444444	0.0	0.0	0.0	2	0.003883
16	AJZ.M		Mine	460000	0	1	1	0.0	1.0	1.0	4.0	0.4	0.520833	0.0	0.0	0.0	8	0.003883
17	ZNG.M		Mine	1000000	0	1	1	0.0	1.0	1.0	4.0	0.368421	0.452381	0.0	0.0	0.0	6	0.003883
18	REZWA...		Mine	2000000	0	1	1	0.0	2.0	2.0	4.0	0.35	0.428571	0.0	0.0	0.0	5	0.003883
19	SORKHE...		Mine	400000	0	1	1	0.0	0.4	0.4	4.0	0.368421	0.452381	0.0	0.0	0.0	6	0.003883
20	AK KAH...		Mine	200000	0	1	1	0.0	0.2	0.2	4.0	0.4	0.520833	0.0	0.0	0.0	8	0.003883
21	PELS.M		Mine	2500000	0	1	1	0.0	2.5	2.5	4.0	0.318182	0.369048	0.0	0.0	0.0	4	0.003883
22	SARAB.M		Mine	150000	0	1	1	0.0	0.15	0.15	4.0	0.344828	0.408333	0.0	0.0	0.0	6	0.003883
23	OPALKA...		Consent...	2600000	1	1	2	30.0	3.0	33.0	3.0	0.413793	0.458333	11.0	0.0	0.0	3	0.005048
24	EHYAA.C		Consent...	3100000	1	2	3	2.5	1.8	4.3	3.0	0.433333	0.5	13.0	0.0	0.0	4	0.007377
25	SIMIDC...		Consent...	2500000	1	2	3	30.0	2.5	32.5	3.0	0.571429	0.708333	4.0	0.0	0.0	3	0.005048
26	SBNK.C		Consent...	1000000	1	2	3	0.75	0.8	1.55	3.0	0.5	0.611111	6.0	0.0	0.0	8	0.007377
27	SBNH.C		Consent...	600000	2	1	3	0.85	0.4	1.25	3.0	0.454545	0.533333	10.0	0.0	0.0	2	0.010872
28	GISDCO.C		Consent...	14750000	0	5	5	0.0	15.0	15.0	3.0	0.438596	0.52	0.0	0.0	0.0	5	0.003883

Fig. 3. The Data laboratory environment used to compute node and network level parameters.

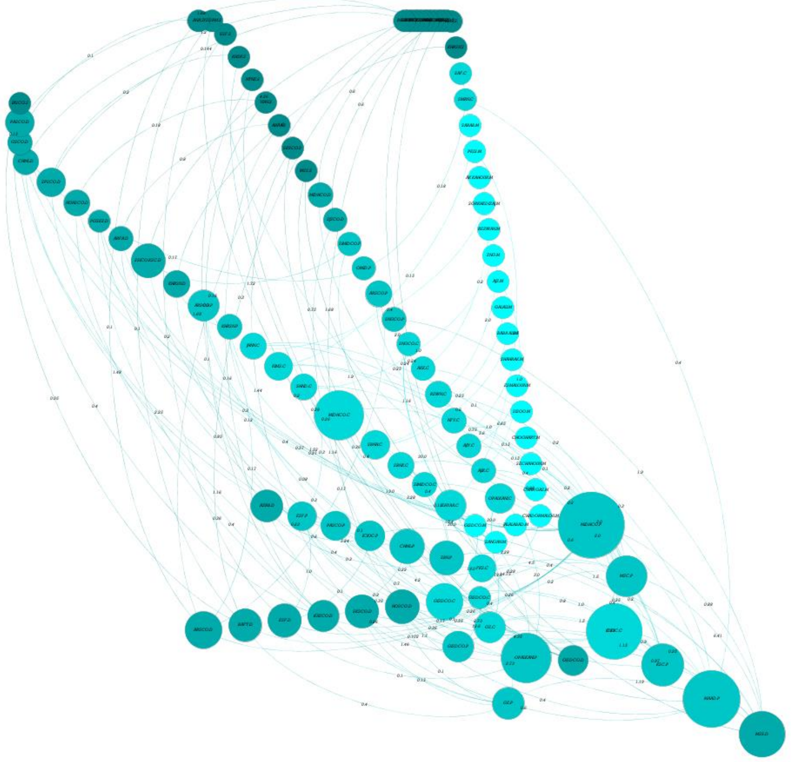


Fig. 4. Mapped network for Iran Steel Industry Chain.

The main nodes in this study are mining, concentrate, pelletization, sponge iron (DRI), steelmaking, and direct links to iron, concentrate, pellets, DRI. Using filters to focus on specific nodes or links based on their attributes, the details within a subset of the presented network examined. Utilizing the attribute panel, attributes of nodes and links visualized. As illustrated in Fig. 4. following experimentation with various layout, the radial axis form selected to represent the desired network. In the given network representing the steel supply chain of Iran, the size of each node indicates its centrality. A color spectrum represents the degree of betweenness. The flow weights of materials between the nodes indicated by the numbers on the links.

5. Research findings and conclusions

The complexity of the SSC network must be determined by the researcher. It is often said that the real-world networks are free-scale. That is, some of the nodes follow a power-law distribution as a model that has a wide range of impacts on the structure and dynamics of complex systems by organizing free-scale networks. Using the statistical tools, Broido and Klaust (2019) show that for thousands of different networks, the lognormal distribution across these networks is a better fit for the data. The Kolmogorov-Smirnov test (Figs. 5 and 6.) shows that the order of the nodes in the target network fits into a lognormal distribution. Therefore, the network in question is a complex network.

In order to answer the questions of this research, we considered 5 types of nodes: mines, Consentrate, pellet, DRI and steel. The desired indicators to show the amount of interactions between nodes are: potential capacity, indegree, outdegree, degree, weighted indegree, weighted outdegree, Weighted Degree, Eccentricity, closnesscentrality, harmonic closness centrality, betweeness centrality, Authority, Hub, modularity_class, pageranks, eigencentrality. The size of each node indicates the degree of centrality. The color spectrum of the nodes shows the degree of betweeness centrality. The weight on the links indicates the weight of the material flow between the nodes. A high degree of centrality in any network indicates low robustness. The betweenness degree represents the role of the node in absorbing and repelling material flow. Therefore, increasing it can improve the degree of robustness.

As evident in the proposed network, the node corresponding to the "P.MIDHCO" entity in the steel chain's pelletizing sector possesses the higher degree of centrality. In the network, the Central Iron Ore node, represented by "ICIOC.C" in constrate sector, exhibit the highest betweenness.

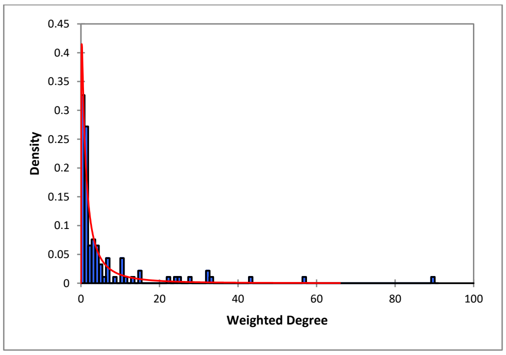


Fig. 5. Distribution of data related to the degree (total degree of input and output) of the SSC network.

Kolmogorov-Smirnov test:

D	0.082
p-value	0.480
alpha	0.05

Test interpretation:
H0: The sample follows a Log-normal distribution
Ha: The sample does not follow a Log-normal distribution

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 47.97%.

Fig. 6. Kolmogorov-Smirnov test for nodes degree data.

This study is a attempted to present Iran's SSC by mapping to an interactive network using graph theory. The distribution fitting of the data related to the node weights shows that the number of available connections, that is, the sum of the input and output degrees of the node, follows the lognormal distribution. Therefore, it can be largely assured that the network under investigation is a interactive network, and propose an agent-based modeling for simulaion of this network for further research. the results of study can be analyzed in several ways:

- An overview of Iran's steel chains.
- Identify the determinants of Iran's SSC from a imprical perspective.
- How to describe variables and relationships between parameters for applied studies.

Due to the advantages, it offers using Iron ore in steel production, steel scrap plays a key role in the steel chain. Given the lack of official data on the production and import of scrap, adapting the proposed network is recommended to account for the involvement of scrap. On the other hand, considering that the SSC of Iran is recognized as a complex adaptive system, simulating proposed network using tools suitable for the network's complexity level is recommended.

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